PLUTONIUM IN SOIL NORTHEAST OF THE NEVADA TEST SITE

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ABSTRACT

Analyses of soil collected at 31 locations northeast of the Nevada Test Site (NTS) as far as south central Idaho, southwestern Wyoming and eastern Utah show higher plutonium levels than expected from global fallout alone. The presence of a second source of plutonium was demonstrated by mass spectrometry, and its origin identified as the NTS. Resolution of the plutonium fallout leads to an uneven dispersion for NTS derived debris. This reinforces the conclusion that safety tests and other detonations which resulted in incomplete fission, conducted from 1956 through 1958, created individual deposition patterns dictated by the wind trajectories at shot time.

INTRODUCTION

Over a period of 14 years (1957-1971, the annual fallout rates c Sr-90 in New York City and Salt Lake City were very similar despite t two and one-half fold difference in mean annual precipitation. Becau of the drier climate in Salt Lake City, a proportionately lower fallc of Sr-90 compared to New York City would have been expected, since pr cipitation is a known scavenger of air-borne debris.

The accumulated deposit was measured at 13 sites in north centra and southeast Utah in 1971 by analyzing soil samples (1). Although the deposited amount was not uniform because of differences in climat and topograpy, there was a clear pattern of higher deposition per uni of the United States. We showed that the fallout from 1957-1971 in New York City and Salt Lake City must have originated from the same global source - the stratosphere. It was reasonable to hypothesize that the Salt Lake City area is a preferential region for direct intrusion of stratospheric air into the troposphere. Prior to 1957, the accumulated Sr-90 deposit in Salt Lake City was 10 - 15 mCi per km² higher than in New York City which implied that Salt Lake City must have received fallout from another source, presumably the Nevada Test Site.

Subsequently, the 13 soil samples collected in 1971 were analyzed for Pu-239-240 and Pu-238 and it was surprising to find higher plutonium levels than predicted from the Sr-90 fallout. By comparing the Pu-239-240 to Sr-90 activity ratios of the Utah soils with the average ratio of thirty-two northern hemisphere soils collected in 1970-71 and containing only global fallout, we estimated that up to 60 percent of the total Pu-239-240 activity deposited at some Utah sites represented a source other than the stratospheric reservoir (2) Soil samples taken at the University of Utah from 1959 through 1971 revealed that the excess plutonium must have been delivered prior to 1959. Mass isotopic analyses indicated that the Nevada Test Site was the probable second source and that twice the level expected from surmised that this plutonium from NTS was predominantly from some of the tests in which plutonium was physically dispersed by high explosives or tests in which little fission occurred.

Since the two reports summarized above were published, two further steps have been taken to determine the extent and distribution of the off-site plutonium contamination from the NTS: (1) during June 1974 soil was sampled at 18 additional sites in Utah, Nevada, Wyoming and Idaho and analyzed for plutonium, and (2) the plutonium fractions representing all sites sampled in 1971 and 1974 were subjected to mass isotope spectrometry as a means of distinguishing the two sources of debris. This report brings together all the data associated with the two sampling efforts.

METHODS

The 1971 and 1974 soil sampling sites are identified in Table 1. Included are values for the mean annual precipitation (3) and altitude. The sites are mapped in Figure 1 where the numbers correspond to those in the first column of Table 1.

The 1971 samples were taken by the core method (4a) to a depth of 30 cm, while both the template (4b) and the core techniques were used to sample to a depth of 15 cm in 1974. Data on depth distributions, acquired following the 1971 sampling, indicated that over

SOIL SAMPLING SITES FOR PLUTONIUM DEPOSITION

Map Site No.	Location	Site	Mean ann. precip. (cm)	Altitude (m)
		Sites Sampled in June 1971 (map location designated by open circle)		
1	Provo, UT	Utah State Hospital	34	1400
2	Salt Lake City, UT	Liberty Park	39	1310
3	Salt Lake City, UT	Univ. of Utah	41	1460
4	Ogden, UT	Cache NF	53	1590
5	Brigham, UT	Tabernacle	46	1370
6	Heber, UT	Tabernacle	39	1710
7	Marion, UT	Cemetery	51	2010
8	Wanship, UT	Rockport Lake Pk.	42	1860
9	Henefer, UT	private meadow	38	1680
10	Uinta Mtns, Ut	Trial Lake area	76	2900
11	Moab, UT	BLM area	20	1620
12	Manti Lasal NF, UT	Geyser Pass	81	2900
13	Manti Lasal NF, UT	Lasal Guard Station	41	2260
		Sites Sampled in June 1974 (map location designated by black dot)		
1	Tybo, NV.	grazing land	<20	1620
2	Cherry Creek, NV	Humboldt NF, Quinn Canyon Range	33	2440
3	Timber Mtn.Pass, NV	Black Cliff area	<20	1710
4	Panaca, NV	grazing land	<20	1460
5	St.George, UT	Dixie NF, Cottonwood Canyon	25	1650
6	Panguitch, UT	Dixie NF, Panguitch Lake	41	2200
7	W.Milford, UT	W.of Frisco Pass & E. of Wah Wah Valley	<20	1460
8	Baker, NV	F. Baker ranch	20	1590
9	Ely, NV	city pasture	27	1950
10	Eureka, NV	grazing land	30	1770
11	Elko, NV	grazing land	23	1650
12	Wendover, NV	west of salt flat	13	1370
13	Veron-Eureka, UT	mountain meadow	38	1830
14	Wales, UT	mountain meadow	41	2380
15	Vernal, UT	meadow	20	1830
16	Robertson, WY	meadow	36	2380
17	Cache NF, UT	Bear River Range, Tony Grove, R.S.	71	2230
18	Twin Falls, ID	Old County Hospital	23	1070

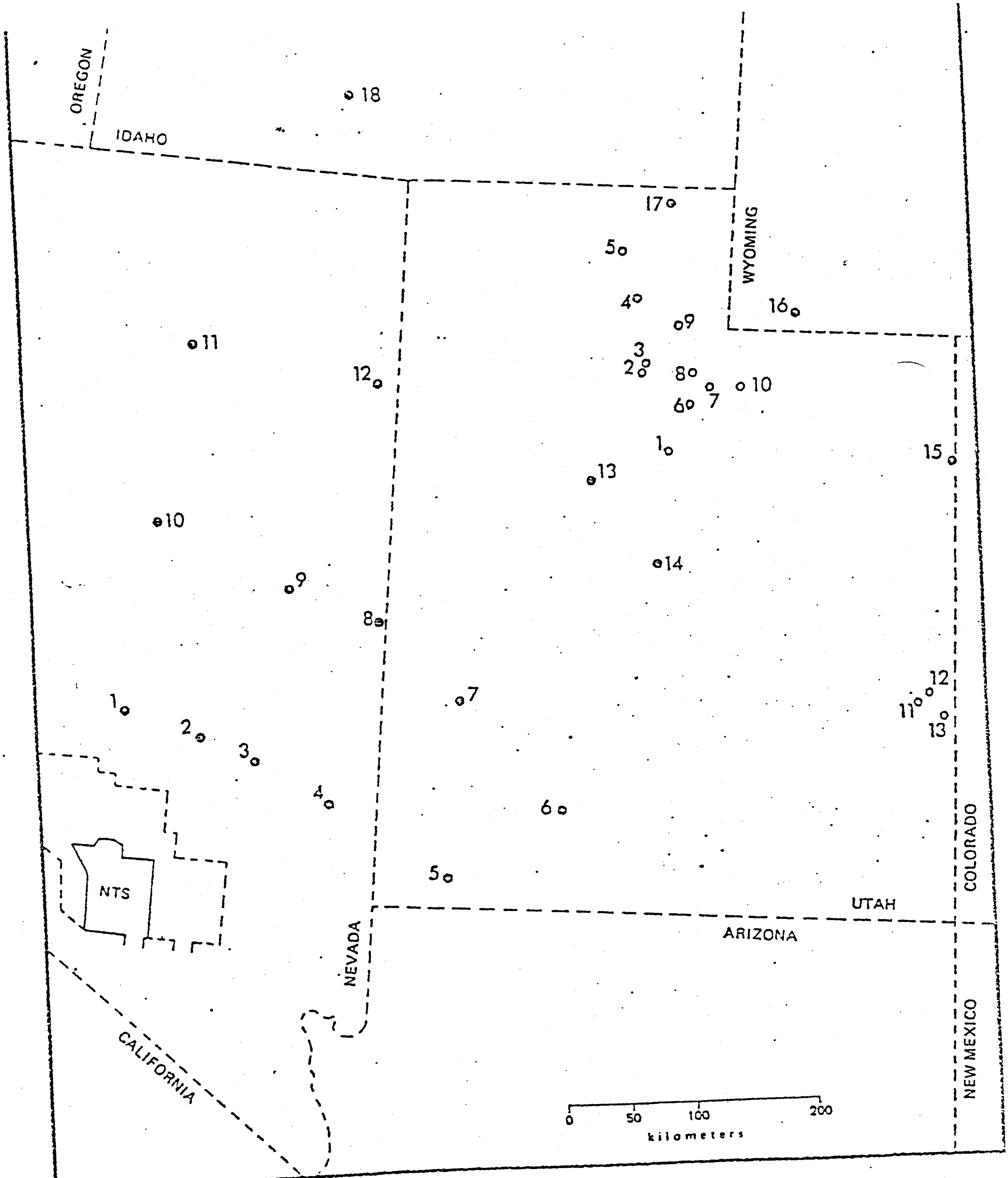

FIG. 1 SOIL SAMPLING SITES: open circles, 1971 samples
dots, 1974 "

95% of the plutonium should be

The sampling method depends upon the soil type and moisture content. The template was used in those situations where a soil core would not hold together.

The 1974 sampling sites were selected from an area defined by the composite trajectory of the winds which existed at the detonation times of 12 safety experiments at NTS. A total of 26 safety tests were carried out at NTS from 1956 through 1958 (5).

As far as could be ascertained, the sites represented undisturbed soil for a period of 20 years. Contacts were made with Forest Service and Soil Conservation personnel who were familiar with the general areas and suggested sites where undisturbed soil could be found.

The soils were prepared for analysis at HASL by drying, crushing, and blending. A five kilogram portion was pulverized (4c). Kilogram aliquots of all the soils were acid extracted. In addition, one hundred gram aliquots of the 1974 soils were analyzed. Ten and one hundred gram aliquots of some of the samples were completely solubilized to compare with the acid extractions. Plutonium was chemically separated and purified by the HASL procedure (6). After electrodeposition on platinum and alpha counting with a silicon barrier detector, the plutonium fractions were isotopically

Radiochemical analyses were carried out at HASL, Teledyne-Isotopes (Palo Alto) and LFE Environmental Analysis Laboratories. Mass spectrometry was performed at Knolls Atomic Power Laboratory, McClellan Central Laboratory and Lawrence Livermore Laboratory.

Aliquots of all the soils were non-destructively analyzed for Cs-137 at HASL by lithium-drifted germanium diode spectrometry (4d).

RESULTS

Single values or averages of replicate analyses for Cs-137, Pu-239,240, and Pu-238 are given in Table 2. Error terms represent one standard deviation due to counting in the case of a single analysis and one standard deviation about the mean in the case of replicate analyses. The activity ratios, Pu-239,240 to Cs-137 and Pu-238 to Pu-239,240 are listed in the table for future reference and the mass ratio, Pu-240 to Pu-239 is given in the last column. Table A in the Appendix provides the individual analytical results for these samples including mass ratios involving Pu-241 and Pu-242.

Some of the Pu-239,240 values in Table 2 show a rather large spread about the mean of replicate analyses, and in one case the error term is close to 50 percent. Our previous experience with

TABLE 2. PLUTONIUM FALLOUT SOILS

June 1971 Sampling
(Sampling Depth 0-30 cm)

Map Site No.	MASL No.	Location	Site	mCi per km² ±σ Cs-137	Pu-239-240	Pu-238	No. of analyses Cs	Pu 239 240	238	Activity Ratios Pu-239,240 / Cs-137	Pu-238 / Pu-239,240	Mass Isotope [illegible]
1	S1718	Provo, UT	institution lawn	140±8	6.0±0.3	0.14±0.01	1	2	1	0.041±0.003	0.024±0.002	0.072
2	S1715	Salt Lake C., UT	Liberty Park	140±8	4.1±0.1	0.11±0.01	1	1	1	0.029±0.002	0.027±0.002	0.088
3	S1711	Salt Lake C., UT	Univ. golf course	170±7	4.9±0.2	0.17±0.01	1	2	1	0.028±0.002	0.035±0.002	0.093
	S1713	" " "	duplicate sampl.	150±8	5.5±0.3	0.16±0.01	1	2	1	0.037±0.003	0.029±0.002	0.085
4	S1712	Ogden, UT	mountain meadow	240±12	5.5±0.1	0.20±0.01	1	1	1	0.023±0.001	0.036±0.002	0.117
5	S1709	Brigham, UT	Tabernacle lawn	150±8	2.9±0.3	0.14±0.01	1	1	1	0.019±0.002	0.048±0.006	0.135
6	S1721	Heber, UT	Tabernacle lawn	100±6	3.0±0.1	0.09±0.01	1	1	1	0.030±0.002	0.031±0.003	0.099
7	S1716	Marion, UT	cemetery	190±7	4.6±0.1	0.15±0.01	1	1	1	0.026±0.001	0.033±0.002	0.101
8	S1719	Wanship, UT	meadow	150±9	2.9±0.1	0.12±0.01	1	1	1	0.019±0.001	0.041±0.004	0.127
9	S1720	Henefer, UT	meadow	150±5	2.9±0.1	0.12±0.01	1	1	1	0.019±0.001	0.041±0.004	0.132
10	S1710	Uinta, Mtns., UT	forest clearing	130±8	2.7±0.1	0.11±0.01	1	1	1	0.021±0.001	0.041±0.004	0.129
11	S1714	Moab, UT	BLM area Spanish Valley	150±5	3.0±0.1	0.08±0.01	1	1	1	0.020±0.001	0.028±0.003	0.124
12	S1717	Geyser Pass, UT	mountain meadow	160±5	3.3±0.1	0.11±0.01	1	1	1	0.021±0.001	0.033±0.003	0.126
13	S1722	Lasal, GS, UT	meadow	89±9	2.3±0.1	0.09±0.01	1	1	1	0.026±0.003	0.040±0.005	0.187

June 1974 Sampling
(Sampling depth 0-15 cm)

Map Site No.	MASL No.	Location	Site	Cs-137	Pu-239-240	Pu-238	Cs	Pu 239 240	238	Pu-239,240 / Cs-137	Pu-238 / Pu-239,240	Mass Isotope [illegible]
1	S1913	Tybo, NV	grazing land	130±6	4.9±1.4	0.21±0.01	1	3	1	0.038±0.011	0.043±0.012	0.091
2	S1912	Cherry Creek, NV	mountain meadow	150±4	9.7±1.9	0.39±0.16	1	4	2	0.065±0.012	0.040±0.018	0.061
3	S1911	Timber Mtn., NV	sparse veg.	87±4	3.8±0.5*	0.21±0.01	1	2	1	0.044±0.006	0.055±0.008	0.084
	S1910	" " "	sagebrush cover	100±2	5.4±1.2	0.28±0.02	1	4	1	0.054±0.012	0.052±0.012	0.074
4	S1909	Panaca, NV	grazing land	130±5	4.5±2.0	0.25±0.02	1	4	1	0.035±0.015	0.056±0.025	0.083
5	S1908	St. George, UT	mountain meadow	140±6	3.2±0.1	0.12±0.01	1	2	1	0.023±0.001	0.038±0.003	0.112
6	S1907	Panguitch, UT	grassed field	94±3	2.4±0.1	0.09±0.01	1	2	1	0.025±0.001	0.038±0.004	0.130
7	S1906	W. Milford, UT	west of Frisco Pass	72±10	2.2±0.2	0.07±0.01	1	2	1	0.030±0.005	0.032±0.005	0.105
8	S1901	Baker, NV	Ranch pasture	82±6	9.0±0.4	0.31±0.07	1	4	2	0.11±0.01	0.034±0.008	0.081
	S1902	" "	duplicate sampl.	83±2	5.0±0.1	0.16±0.02	1	2	1	0.060±0.002	0.032±0.004	0.073
9	S1900	Ely, NV	City pastureland	120±2	5.4±0.5	0.21±0.02	1	2	1	0.045±0.004	0.039±0.005	0.083
10	S1899	Eureka, NV	grazing land	120±8	19.5±0.5	0.51±0.10	1	3	2	0.16±0.01	0.026±0.005	0.063
11	S1898	Elko, NV	grazing land	110±7	2.4±0.4	0.12±0.01	1	2	1	0.022±0.004	0.050±0.009	0.141
12	S1897	Wendover, NV	west of salt flat	110±2	2.1±0.1	0.09±0.01	1	2	1	0.019±0.001	0.043±0.005	0.168
13	S1892	Vernon-Eureka, UT	mountain meadow	150±6	4.2±0.4	0.15±0.04	1	3	2	0.028±0.003	0.036±0.010	0.110
	S1893	" " "	duplicate sampl.	140±3	4.5±1.6	0.12±0.01	1	3	1	0.032±0.011	0.027±0.010	0.122
14	S1891	Wales, UT	mountain meadow	130±5	3.7±1.1	0.14±0.01	1	3	1	0.028±0.008	0.038±0.012	0.082
15	S1890	Vernal, UT	meadow	77±5	1.7±0.3	0.07±0.01	1	2	1	0.022±0.004	0.041±0.009	0.115
16	S1888	Robertson, WY	meadow	140±4	3.5±0.7	0.12±0.06	1	3	2	0.025±0.005	0.034±0.018	0.103
	S1889	" "	Aspen grove	150±5	4.7±1.9	0.13±0.01	1	3	1	0.031±0.013	0.028±0.011	0.097
17	S1887	Cache N.F., UT	Tony Grove meadow	230±4	4.3±0.1	0.20±0.02	1	2	1	0.019±0.001	0.046±0.005	0.141
18	S1886	Twin Falls, ID	Co. Hospital lawn	85±5	2.4±0.3	0.13±0.01	2	4	1	0.028±0.004	0.054±0.008	0.103

*Not included: single MASL value of 16.1.

was less than twenty percent (7). There are five sites where duplicate samples were taken. Table 3 shows the sampling reproducibility (the difference between pairs expressed as a percent of the mean) for the three isotopes and the Pu-240 to Pu-239 mass ratio. For Pu-239-240, the sampling reproducibility ranged from 7 to 57 percent whereas in previous studies a sampling reproducibility of 20 percent or less was usually encountered (7). The corresponding values for Cs-137 and the mass ratio Pu-240 to Pu-239 are less than 15 percent. The most plausible explanation for large analytical and sampling errors associated with the plutonium analyses is that the plutonium containing particles are not uniformly distributed and that in some samples relatively few particles contain the bulk of the plutonium activity. It would appear that we are dealing with the so-called "hot particle problem" which has plagued the EPA in their off-site plutonium in soil program (8). Obviously the much larger samples collected and analyzed in this work were still not adequate to entirely overcome this problem.

In analyzing soil containing plutonium from NTS activities, the possibility exists that some fraction of the plutonium can

TABLE 3. DUPLICATE SAMPLING

Map Site	Sampling Year	Site	Percent Reproducibility			
						Mass Ratio
			Cs-137	Pu-239,240	Pu-238	Pu-240 to Pu-239
3	1971	Salt Lake C., UT	12	12	6	1
3	1974	Timber Mtn., NV	14	35	28	13
8	"	Baker, NV	1	57	64	10
13	"	Vernon-Eureka, UT	7	7	22	10
16	"	Robertson, WY	7	29	8	6

not be extracted with acid. In this study there were ten pairs of data which could be used to compare acid extraction with complete dissolution (see Table B-1 in the Appendix). Using a two-sided T-test, $\alpha = 0.05$, which would indicate that at the 95 percent confidence level, acid extraction was as effective as complete dissolution in recovering plutonium. Individual pairs of data, however, show large variations which are only plausible if the "hot particle" explanation is invoked. Using the same statistical test we compared the acid extraction of 100 and 1000 gram aliquots and the complete dissolution of 10 and 100 gram aliquots (see Tables B-2 and B-3 in the Appendix). No difference between the sets of data in either case, at the 95 percent confidence level, was observed.

In addition to blind replicates, aliquots of pre-bomb (or blank) soil and reference soils were analyzed as indicators of analytical quality. No evidence of contamination during analyses was found. Tables C-1 through C-3 in the Appendix summarize the supporting data for this observation.

DISCUSSION

Although the emphasis in this work is on plutonium deposited northeast of the Nevada Test Site, the soils sampled were analyzed for the fission product Cs-137 to compare distributions. The

Cs-137 results in mCi per km² are mapped in Figure 2 and show a random but fairly uniform deposition pattern. The highest values reflect high amounts of precipitation and the lowest values are from the drier areas. Although there is no obvious gradation from high to low deposits with increasing distance from the NTS, presumably some variable fraction of the total Cs-137 measured originated from nuclear tests in Nevada. The Pu-239,240 to Cs-137 ratio for soils containing only global fallout is 0.016 ± 0.003 (10). Table 2 shows that this ratio is higher in almost all cases indicating the presence of plutonium from a source other than global fallout.

The total (measured) deposit of Pu-239,240 mapped in Figure 3 does not show a clear pattern of decreasing levels with distance from NTS. From a deposit of 1.7 mCi per km² at Vernal, UT to 19.5 mCi per km² at Eureka, NV, these values range from about equal to five times the levels measured elsewhere in the conterminous United States (11).

By using mass spectrometry, we were able to determine the plutonium isotopic composition of these integrated fallout samples. The ratio of Pu-240 to Pu-239 is given for each site in Table 2. The mass isotopic composition of global fallout plutonium in soil has been determined from analysis of 65 soil samples collected throughout the world during 1970-1971 (12). The global mean atom

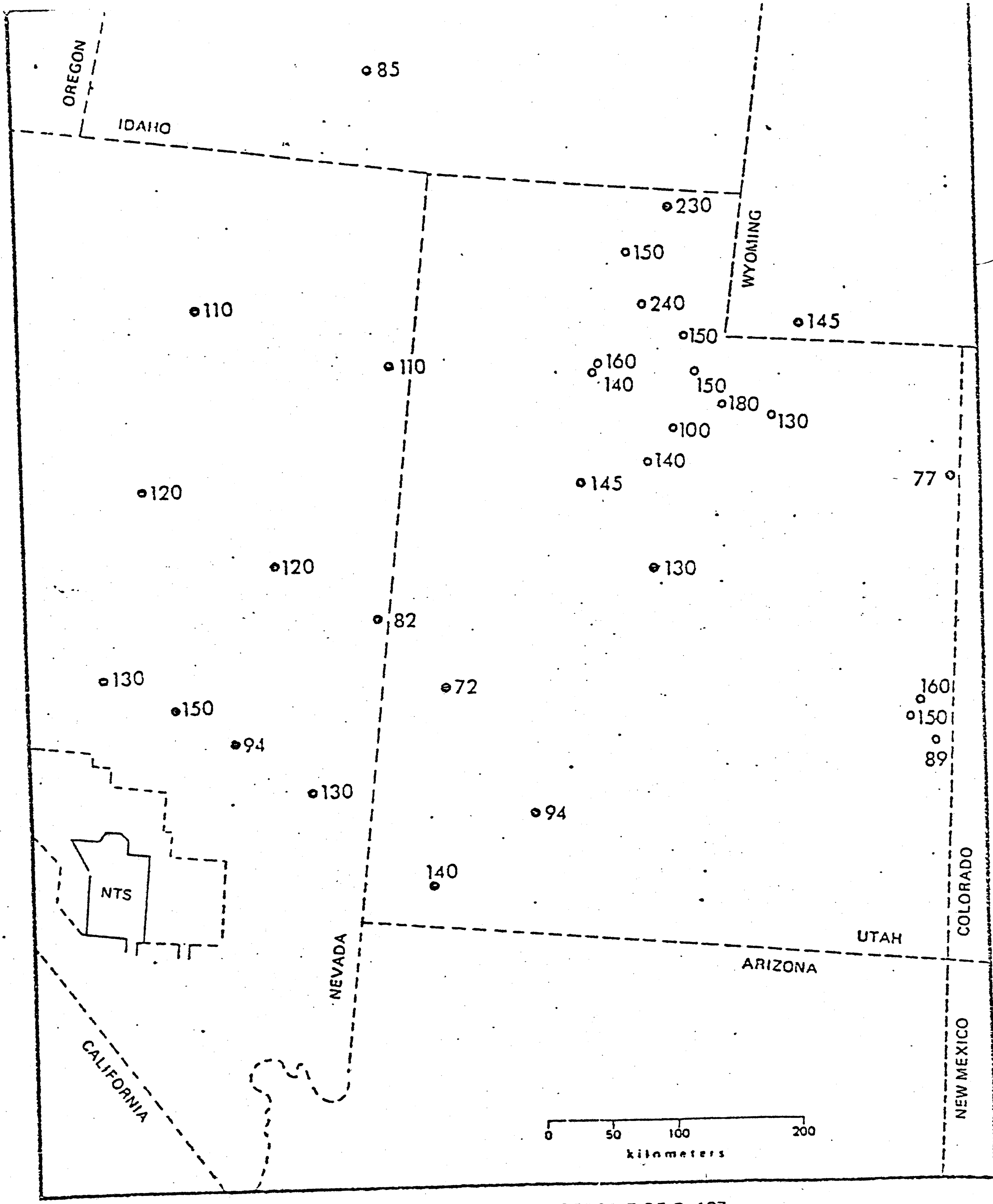

FIG. 2 CUMULATIVE TOTAL DEPOSIT OF Cs-137
(mCi per km^2)

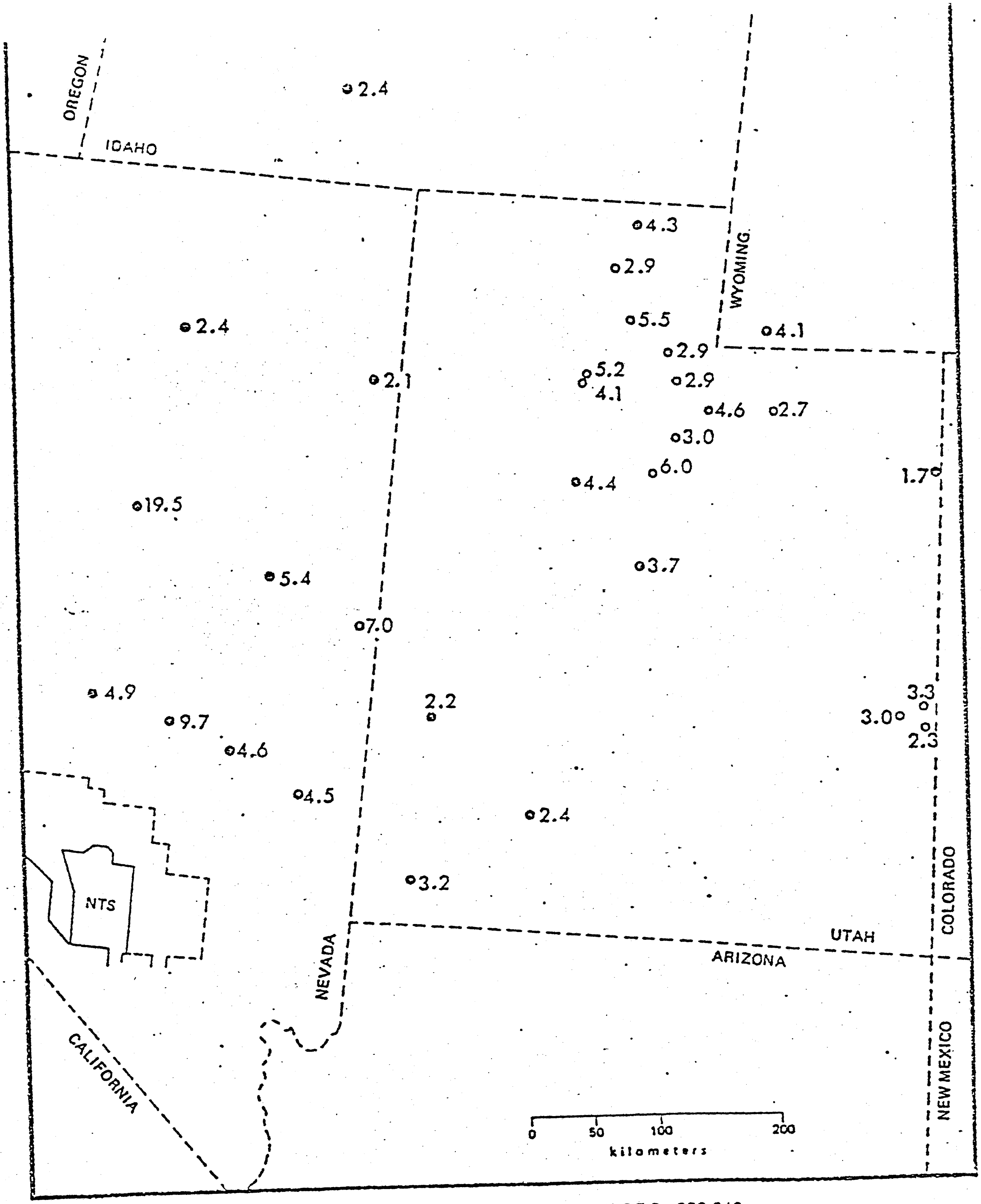

FIG. 3 CUMULATIVE TOTAL DEPOSIT OF Pu-239,240
($\bar{m}$Ci per km^2)

ratio for Pu-240 to Pu-239 is 0.176±0.014. It has been demonstrated that by mass spectrometric analysis, it is possible to differentiate between global fallout plutonium and plutonium from another source (13.14). It is obvious from the last column in Table 2 that most of the soil samples contain plutonium from a second source. If the mass isotopic composition of plutonium from two sources is sufficientl different, a mixture of these sources can be resolved by applying the following equation (12).

$$\frac{(\text{Pu activity})_1}{(\text{Pu activity})_2} = \frac{(R_2-R)}{(R-R_1)} \quad \frac{(1+3.6R_1)}{(1+3.6\ R_2)}$$

where R is the Pu-240 to Pu-239 atom ratio of the mixture and R_1 and R_2 the ratios for source 1 and 2, respectively. We used a Pu-240 to Pu-239 value for NTS of 0.05±0.01 (12) and for global fallout, 0.18±0.01 (12). Based on this relationship it is straightforward to calculate the global and the excess plutonium deposit for each site. These values are given in Table 4. The last column of this table shows the percent of the total (measured) deposit of plutonium that is attributed to the NTS. All but two of the sites show the presence of NTS plutonium.

The deposition values for global fallout Pu-239,240 are mapped in Fig. 4 and show a random, rather homogeneous pattern with higher value

TABLE 4 COMPONENTS OF PLUTONIUM FALLOUT IN SOIL

(Determined from the Mass Ratio: Pu-240 to Pu-239)

1971 Samples

Map Site No.	Location	mCi Pu-239,240 per km² Global	Excess	% of Total Attributed to NTS
1	Provo, UT	1.2±0.7	4.8±0.8	80±14
2	Salt Lake C., UT	1.5±0.4	2.6±0.4	63±10
3	Salt Lake C., UT	1.7±0.5	3.5±0.6	67±12
4	Ogden, UT	3.3±0.3	2.2±0.3	40±5
5	Brigham, UT	2.1±0.2	0.8±0.4	27±14
6	Heber, UT	1.4±0.3	1.5±0.3	52±10
7	Marion, UT	2.1±0.4	2.5±0.4	52±9
8	Wanship, UT	2.0±0.2	0.9±0.2	32±6
9	Henefer, UT	2.0±0.2	0.9±0.2	30±6
10	Uinta, Mtns., UT	1.8±0.1	0.9±0.1	32±6
11	Moab, UT	2.0±0.1	1.1±0.1	34±5
12	Geyser Pass, UT	2.2±0.1	1.1±0.2	33±5
13	Lasal, G.S., UT	2.3±0.1	0.0	0

1974 Samples

Map Site No.	Location	Global	Excess	% of Total Attributed to NTS
1	Tybo, NV	2.0±0.7	2.9±1.6	60±37
2	Cherry Creek, NV	1.1±0.5	8.6±2.0	89±27
3	Timber Mtn., NV	1.0±0.4	2.8±0.6	75±19
	duplicate sampl.	1.9±0.5	3.6±1.3	67±28
4	Panaca, NV	1.5±0.7	3.0±2.1	67±55
5	St. George, UT	1.8±0.2	1.4±0.2	44±6
6	Panguitch, UT	1.7±0.1	0.7±0.2	31±7
7	W. Milford, UT	1.1±0.1	1.1±0.2	49±12
8	Baker, NV	2.7±0.8	6.3±0.8	70±10
	duplicate sampl.	1.2±0.3	3.8±0.3	76±6
9	Ely, NV	1.7±0.3	3.7±0.6	68±13
10	Eureka, NV	2.8±1.0	16.7±1.1	86±6
11	Elko, NV	1.8±0.3	0.6±0.5	24±22
12	Wendover, NV	1.9±0.1	0.2±0.2	8±8
13	Vernon-Eureka, UT	2.3±0.3	1.9±0.5	45±12
	duplicate sampling	2.8±1.0	1.7±1.9	37±44
14	Wales, UT	1.2±0.4	2.5±1.2	69±38
15	Vernal, UT	1.0±0.2	0.7±0.4	43±22
16	Robertson, WY	1.7±0.5	1.8±0.6	52±20
	duplicate sampl.	2.1±1.0	2.6±2.1	54±50
17	Cache N.F., UT	3.3±0.2	1.0±0.2	24±5
18	Twin Falls, ID	1.1±0.3	1.3±0.4	52±18

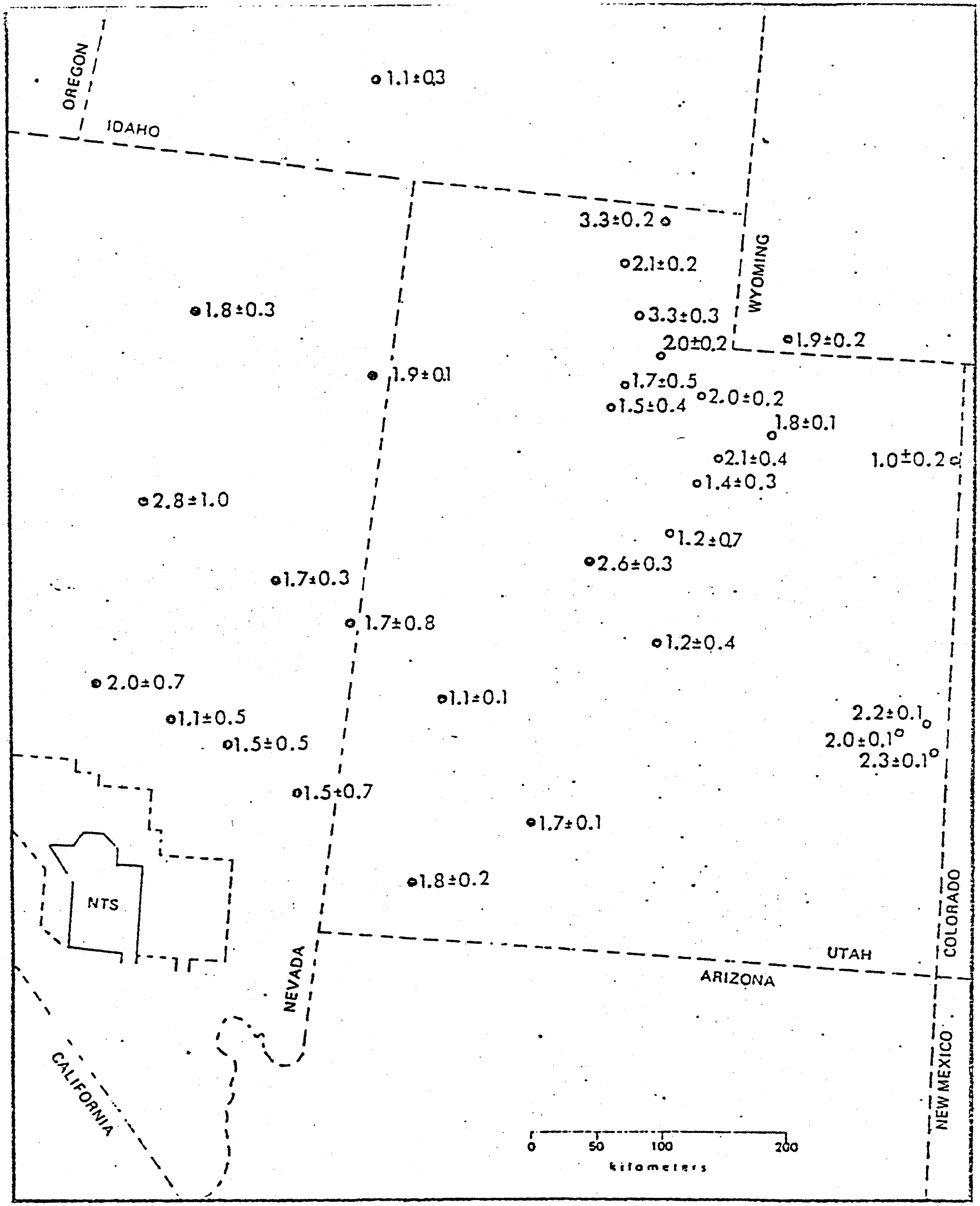

FIG. 4 CUMULATIVE GLOBAL FALLOUT DEPOSIT OF Pu-239,240
(mCi per km^2)

again reflecting higher amounts of rainfall. The ratios of the Cs-137 values to these calculated global fallout Pu-239,240 values average 0.014±0.005 which is in good agreement with the ratio observed in soils containing only global fallout (10). This means that the measured Cs-137 deposits and the calculated global fallout Pu-239,240 deposits for these sites reflect debris originating from the stratosphere, within the limits of error imposed upon these values.

Perhaps the most convincing evidence we have that the excess or second source of plutonium is from NTS safety tests and other detonations which resulted in incomplete fission, is the radiochemical and mass isotope spectrometric data we have on a series of soil samples collected at the University of Utah from 1959 through 1971. Table 5 presents these data as well as data for three soils from Cedar City, UT from 1963 through 1965. The mass ratio of Pu-240 to Pu-239 at the University site is 0.050 in 1959 and increases to 0.084 in 1971. This indicates that the second source of plutonium was deposited prior to 1959 and the increase in the ratio reflects dilution of this debris with global plutonium fallout. Since all of the safety tests at NTS were conducted before 1959, it seems reasonable to attribute a substantial portion of the excess plutonium to this source. The Cedar City data show that the NTS contribution to the total measured plutonium deposit is much less in this area compared to the Salt Lake City area.

TABLE 5. CHRONOLOGY OF PLUTONIUM DEPOSITION

Year	Total Pu-239,240 (mCi/km^2)	Mass Isotope Ratio Pu-240/Pu-239	Mass Spec. Lab.	Global Fallout Pu-239,240 (mCi/km^2)	Excess Pu-239,240 from NTS (mCi/km^2)	% of Total Fallout Pu from NTS
			University of Utah			
1971	5.2	0.084	KAPL	1.7	3.6	69
1965	4.7	0.082	LLL	1.4	3.3	70
1964	4.9	0.079	LLL	1.4	3.5	71
1963	4.5	0.060	KAPL	0.5	4.0	89
1962	4.2	0.058	KAPL	0.4	3.8	90
1960	3.8	0.051	KAPL	<0.4	3.4	>90
1959	4.2	0.050	LLL	<0.4	3.8	>90
			Cedar City, Utah			
1965	1.4	0.141	LLL	1.1	0.3	21
1964	1.5	0.132	KAPL	1.1	0.4	27
1963	1.4	0.121	KAPL	0.9	0.5	36

pattern from NTS. Considering the errors associated with these data, we attempted to draw isopleths to show the dispersion pattern. The 2 mCi per km^2 isopleth was the lower limit but it is obvious that a much wider area has received plutonium fallout from NTS at levels less than 2 mCi per km^2. The soil sampling that has been carried out to date does not encompass a large enough area and is not sufficiently dense to provide a reliable value for the total amount of plutonium released from the NTS. Furthermore, it is clear that the dispersion pattern is more complex than we are able to show. Apparently each individual detonation produced a separate downwind deposition pattern and the composite picture contains small area highs and lows that can not be defined by the data available here. Within the isopleths that we have drawn, however, we estimate by contouring that 700 curies of Pu-239-240 from NTS have deposited northeast of the test site as far as the Salt Lake City area. By comparison the global fallout Pu-239,240 within the same area amounts to about 250 curies.

Twelve of the twenty-six safety tests had wind trajectories that followed a northeast pattern from NTS. The wind trajectories for the remaining fourteen detonations overlap the other three segments of the compass. Our coverage, therefore, from an inventory

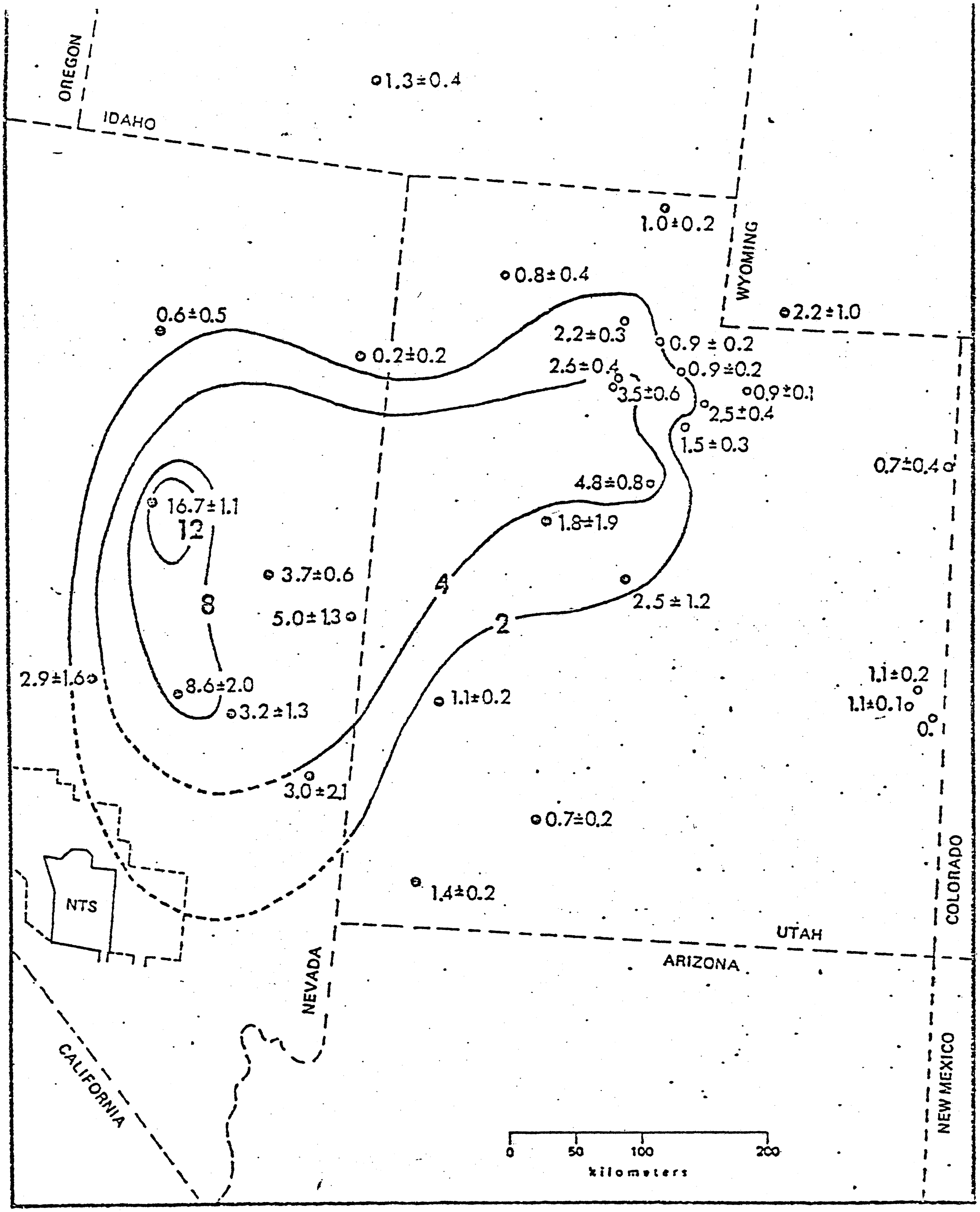

FIG. 5 CUMULATIVE NTS DEPOSIT OF Pu-239,240
(mCi per km^2)

As of 1974

... plutonium but the dispersion does not show a smoothly decreasing pattern with distance from NTS. The twelve safety tests which had wind trajectories northeast of the NTS apparently created distinctly different deposition patterns. Within the 2 mCi per km² isopleth which extends northeast as far as the Salt Lake City area, about 700 curies of NTS Pu-239,240 has deposited as compared to about 250 curies of global fallout Pu-239,240. The sampling coverage and density, however, are inadequate to show the apparently broader extent of off-site plutonium contamination from NTS.

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Mr. Kermit Larson of the Forest Service in Ogden, UT and Dr. Theron Hutchings of the Soil Conservation Service in Salt Lake City provided the names of field personnel who designated suitable sampling areas.

The sampling phase was carried out with the field assistance and advice of Frank Jakubowski and Harold Peer of the Environmental Protection Agency, National Environmental Research Center, Las Vegas. Mr. Wayne Bliss, head of the off-site monitoring operations at EPA-LV, provided the field support and guidance.

standpoint is very limited. We know, for example, that the soil we sampled at Burbank, CA in 1970 includes some plutonium from NTS because the Pu-240 to Pu-239 mass ratio was 0.144 compared with the average of 0.176±0.014 for global fallout (12). The total Pu-239,240 deposit was only 0.7 mCi per km² so the NTS contribution is considerably less at this site than in the Salt Lake City area, by comparison.

CONCLUSIONS

Integrated plutonium fallout levels as measured in soil samples taken northeast of the Nevada Test Site in 1971 and 1974 are in most cases several times higher than expected from global fallout. Mass spectrometric analysis of the radiochemically separated plutonium fractions demonstrates the presence of a second source of plutonium. A sequence of soil samples collected from 1959 to 1971 at the University of Utah indicate that this second source of plutonium fallout was the safety tests and other detonations where little or no fissioning occurred, which were carried out from 1956 through 1958 at the NTS. Resolution of the plutonium fallout levels into global and NTS source components leads to a reasonably uniform global fallout pattern as far north as Twin Falls, ID and as far east as Vernal, UT. Twenty-nine of the thirty-one sites sampled

Mass Spectrometric analyses were performed at Knolls Atomic Power Laboratory under the direction of Leonard Dietz and Frank Rourke (Mass Spectrometry Programs), at Lawrence Livermore Laboratory by Jene Dupzyk and Riley Carver (Radiochemistry Division) and at McClellan Central Laboratory under the direction of Col. William Meyers.

The analyses at HASL were carried out by N.Y. Chu, J. Feldstein and C. Sanderson.

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A P P E N D I X

TABLE A

BASIC DATA FOR SOIL SAMPLES COLLECTED FOR PLUTONIUM FROM NTS

Map Site	NASL No.	Site	Sampl'g Date	Depth (cm)	No. Cores or Cuts	Total Area Sampled (cm²)	Total Air Dried wt. (kg)	Anal. Lab.	Grams Anal.	Method	dpm per g dry soil ±σ(·) Cs-137	Pu-239-240	Pu-238	nCi per km² Cs-137	Pu-239,240	Pu-238	Mass Isotope Ratio 240/239	241/239	242/239	Mass Spec. Lab.
1	S1718	Provo, UT	6-15-71	0-30	10	620	29.3	NASL	254	Ge-Li	0.67±6			140						
								IPA	1000	Acid Extr.		0.028±1	0.00047±6		5.8	0.14	0.072	.0026	-	LLL
								LFE	100	Complete Sol'n.		0.030±5			6.3					
2	S1715	Salt Lake City, UT	6-18-71	0-30	10	620	21.0	NASL	225	Ge-Li	0.92±6			140						
								IPA	1000	Acid Extr.		0.027±3	0.00075±6		4.1	0.11	.058	.0033	.0017	KAPL
3	S1711	Univ. of Utah, UT	6-17-71	0-30	10	620	25.6	NASL	276	Ge-Li	0.92±6			170						
								IPA	1000	Acid Extr.		0.028±3	0.00093±6		5.2	0.17	.081	.0029	.0015	KAPL
								LFE	3000	" "		0.025±1			4.6		.055	.0033	.0016	HCL
-	S1713	Duplicate Sampling	6-17-71	0-30	10	620	25.8	NASL	268	Ge-Li	0.81±5			150						
								IPA	1000	Acid Extr.		0.025±3	0.00034±6		5.3	0.16	.085	.0030	.0015	KAPL
								LFE	100	Complete Sol'n.		0.031±2			5.8					
4	S1712	Ogden, UT	6-18-71	0-30	10	620	33.0	NASL	364	Ge-Li	1.01±5			240						
								IPA	1000	Acid Extr.		0.023±1	0.00083±4		5.5	0.20	.117	.0046	-	LLL
5	S1709	Brigham, UT	6-15-71	0-30	10	620	26.3	NASL	344	Ge-Li	0.84±5			150						
								IPA	1000	Acid Extr.		0.017±10	0.00077±4		2.9	0.14	.135	.0052	.0025	KAPL
6	S1721	Heber, UT	6-15-71	0-30	10	620	22.5	NASL	316	Ge-Li	0.54±6			100						
								IPA	1000	Acid Extr.		0.019±3	0.00058±6		3.0	0.09	.099	.0038	.0020	KAPL
7	S1716	Marion, UT	6-16-71	0-30	10	620	24.1	NASL	295	Ge-Li	1.02±6			180						
								IPA	1000	Acid Extr.		0.026±1	0.00038±4		4.6	0.13	.101	.0038	.0022	KAPL
8	S1719	Wanship, UT	6-16-71	0-30	10	620	31.4	NASL	352	Ge-Li	0.67±6			150						
								IPA	1000	Acid Extr.		0.013±1	0.00051±5		2.9	0.12	.127	.0049	.0023	KAPL
9	S1720	Henefer, UT	6-17-71	0-30	10	620	22.5	NASL	318	Ge-Li	0.94±3			150						
								IPA	1000	Acid Extr.		0.013±1	0.00072±4		2.9	0.12	.132	.0054	.0029	KAPL
10	S1710	Uinta Mtns, UT	6-16-71	0-30	10	620	16.5	NASL	267	Ge-Li	1.05±6			130						
								IPA	1000	Acid Extr.		0.022±1	0.00085±5		2.7	0.11	.128	.0048	.0027	KAPL
11	S1714	Moab-BLM, UT	6-14-71	0-30	1	930	30.8	NASL	353	Ge-Li	1.01±3			150						
								IPA	1000	Acid Extr.		0.020±1	0.00056±6		3.0	0.08	.124	.0044	.0027	KAPL
12	S1717	Manti-Lasal-Geyser P.	6-14-71	0-30	10	620	21.3	NASL	294	Ge-Li	1.04±3			160						
								IPA	1000	Acid Extr.		0.021±1	0.00073±6		3.3	0.11	.126	.0045	.0027	KAPL
13	S1722	Manti-Lasal-Guard S.	6-14-71	0-30	10	620	23.0	NASL	314	Ge-Li	0.54±10			89						
								IPA	1000	Acid Extr.		0.014±1	0.00056±5		2.3	0.09	.187	.0069	.0033	KAPL
1	S1913	Tybo, NV	6-4-74	0-15	3	675	13.3	NASL	379	Ge-Li	1.44±5			130						
								NASL	100	Acid Extr.		0.041±9			3.6					
								LFE	1000	" "		0.054±3	0.0024±6		4.7	0.21	.091	.0035	.0013	KAPL
								LFE	100	Compl. Sol'n.		0.070±3			6.3					
2	S1912	Cherry Creek, NV	6-4-75	0-15	3	675	17.0	NASL	384	Ge-Li	1.32±3			150						
								NASL	100	Acid Extr.		0.101±7			11.4					
								LFE	1000	" "		0.095±3	0.0025±6		10.8	0.28	0.061	.0022	.0010	KAPL
								LFE	100	Compl. Sol'n.		0.062±4	0.0044±15		7.1	0.50				
								NASL	10	" "		0.082±8			9.4					
3	S1911	Timber Mtn, NV	6-4-75	0-15	1	1000	9.7*	NASL	348	Ge-Li	1.98±5			87						
								NASL	100	Acid Extr.		0.369±8			16.1					
								LFE	1000	" "		0.096±3	0.0048±5		4.2	0.21	.074	.0026	.0011	KAPL
					(* Rocks Removed)			NASL	100	" "		0.041±6			3.5					
-	S1910	Duplicate Sampling	6-4-75	0-15	1	1000	12.2*	NASL	332	Ge-Li	1.85±2			100						
								NASL	100	Acid Extr.		0.058±7			3.8					
								LFE	1000	" "		0.101±3	0.0050±5		5.6	0.28	.034	.0037	.0012	KAPL
								NASL	100	" "		0.107±5			3.9					
					(* Rocks Removed)			LFE	100	Compl. Sol'n.		0.118±3			6.5					
4	S1909	Panaca, NV	6-5-75	0-15	3	675	15.2	NASL	344	Ge-Li	1.29±6			130						
								NASL	100	Acid Extr.		0.030±9			3.1					
								LFE	1000	" "		0.074±3	0.0025±7		7.5	0.25	.083	.0031	.0037	KAPL
								NASL	100	" "		0.032±6			3.2					
								LFE	100	Compl. Sol'n.		0.042±3			4.3					
5	S1908	St. George, UT	6-5-74	0-15	2	800	14.5	NASL	369	Ge-Li	1.59±6			140						
								NASL	100	Acid Extr.		0.038±7			3.1					
								LFE	1000	" "		0.040±6	0.0015±6		3.7	0.12	.112	.0043	.0039	KAPL
6	S1907	Panguitch, UT	6-5-74	0-15	10	620	12.5	NASL	255	Ge-Li	1.01±3			94						
								NASL	100	Acid Extr.		0.028±8			2.5					
								LFE	1000	" "		0.026±6	0.0009±14		2.4	0.09	.130	-	-	KAPL

TABLE A

BASIC DATA FOR SOIL SAMPLES COLLECTED FOR PLUTONIUM FROM NTS (Cont'd)

Map Site	NASL No.	Site	Sampl'g Date	Depth (cm)	No. Cores or Cuts	Total Area Sampled (cm²)	Total Air Dried wt. (kg)	Anal. Lab.	Grams Anal.	Method	dpm per g dry soil ±σ(?) Cs-137	Pu-239,240	Pu-238	nCi per km² Cs-137	Pu-239,240	Pu-238	Mass Isotope Ratio 240/239	241/239	242/239
7	S1906	W. Milford, UT	6-6-74	0-15	2	800	14.6	NASL	371	Ge-Li	0.83±16			72					
								NASL	100	Acid Extr.		0.025±3			2.1				
								LFE	1000	" "		0.029±3	0.0009±10		2.4	0.07	.106	.0037	.0021
8	S1901	Baker, NV	6-6-74	0-15	10	620	12.8	NASL	300	Ge-Li	0.89±7			82					
								NASL	100	Acid Extr.		0.102±6			9.5				
								LFE	1000	" "		0.091±5	0.0028±10		8.5	0.26	.081	.0035	.0007
								LFE	100	Compl. Sol'n.		0.097±3	0.0039±16		9.0	0.36			
								NASL	10	" "		0.093±7			9.1				
"	S1902	Duplicate Sampling	6-6-74	0-15	10	620	13.1	NASL	296	Ge-Li	0.37±3			83					
								NASL	100	Acid Extr.		0.032±10			3.0				
								LFE	1000	" "		0.053±4	0.0017±10		4.9	0.16	.073	.0027	.0012
9	S1900	Ely, NV	6-7-74	0-15	10	620	11.6	NASL	247	Ge-Li	1.33±2			120					
								NASL	100	Acid Extr.		0.070±5			5.8				
								LFE	1000	" "		0.061±4	0.0025±9		5.1	0.21	.083	.0033	.0012
10	S1899	Eureka, NV	6-7-74	0-15	3	675	13.7	NASL	347	Ge-Li	1.30±7			120					
								NASL	100	Acid Extr.		0.209±9			19.0				
								LFE	1000	" "		0.215±2	0.0048±4		19.6	0.44	.063	.0025	.0005
								LFE	100	Compl. Sol'n.		0.219±3	0.0064±12		20.0	0.58			
11	S1898	Elko, NV	6-8-74	0-15	10	620	13.6	NASL	289	Ge-Li	1.12±6			110					
								NASL	100	Acid Extr.		0.021±8			2.1				
								LFE	1000	" "		0.027±3	0.0012±8		2.7	0.12	.141	.0055	.0030
12	S1897	Wendover, UT	6-8-74	0-15	2	800	15.6	NASL	367	Ge-Li	1.25±2			110					
								NASL	100	Acid Extr.		0.026±8			2.2				
								LFE	1000	" "		0.023±3	0.0010±9		2.0	0.09	.168	-	-
13	S1892	Vernon-Eureka, UT	6-9-74	0-15	10	620	12.1	NASL	277	Ge-Li	1.69±4			150					
								NASL	100	Acid Extr.		0.043±10			3.9				
								LFE	1000	" "		0.047±3	0.0014±9		4.1	0.12	.110	.0037	.0023
								LFE	100	Compl. Sol'n.		0.052±4	0.0020±24		4.6	0.18			
"	S1893	Duplicate Sampling	6-9-74	0-15	10	620	13.2	NASL	279	Ge-Li	1.47±2			140					
								NASL	100	Acid Extr.		0.067±10			6.4				
								LFE	1000	" "		0.038±3	0.0012±9		3.6	0.12	.122	.0042	.0025
								NASL	100	" "		0.038±6			3.6				
14	S1891	Wales, UT	6-9-74	0-15	2	800	8.2	NASL	239	Ge-Li	2.73±4			130					
								NASL	100	Acid Extr.		0.092±10			4.3				
								LFE	1000	" "		0.093±4	0.0029±5		4.3	0.14	.082	.0029	.0017
								NASL	10	Compl. Sol'n.		0.051±17			2.4				
15	S1890	Vernal, UT	6-10-74	0-15	10	620	14.9	NASL	364	Ge-Li	0.71±6			77					
								NASL	100	Acid Extr.		0.014±11			1.3				
								LFE	1000	" "		0.018±3	0.0006±12		1.9	0.07	.116	.0041	.0022
16	S1888	Robertson, WY	6-11-74	0-15	10	620	12.0	NASL	314	Ge-Li	1.41±3			140					
								NASL	100	Acid Extr.		0.031±13			2.7				
								LFE	1000	" "		0.043±4	0.0009±14		3.7	0.08	.103	.0037	.0020
								LFE	100	Compl. Sol'n.		0.045±4	0.0018±14		4.0	0.16			
"	S1889	Duplicate Sampling	6-11-74	0-15	10	620	12.4	NASL	239	Ge-Li	1.70±3			150					
								NASL	100	Acid Extr.		0.031±11			2.8				
								LFE	1000	" "		0.051±3	0.0014±8		4.6	0.13	.097	.0038	.0015
								NASL	100	" "		0.073±5			6.6				
17	S1887	Cache NF, UT	6-11-74	0-15	10	620	11.0	NASL	271	Ge-Li	2.82±2			230					
								NASL	100	Acid Extr.		0.053±10			4.2				
								LFE	1000	" "		0.055±4	0.0026±9		4.4	0.20	.141	.0053	.0027
18	S1886	Twin Falls, ID	6-12-74	0-15	10	620	10.4	NASL	262	Ge-Li	1.15±3			88					
								NASL	268	"	1.03±6			82					
								NASL	100	Acid Extr.		0.034±12			2.5				
								NASL	100	" "		0.027±7			2.0				
								LFE	1000	" "		0.034±3	0.0017±5		2.7	0.13	.103	.0067	.0021
								NASL	100	" "		0.032±6			2.4				

TABLE B-1. COMPARISON BETWEEN ACID EXTRACTION AND COMPLETE DISSOLUTION IN SOIL Pu ANALYSIS

HASL No.	Site	mCi Pu-239,240 per km²		No. of Analyses	
		Acid Extr.	Complete Sol'n.	Acid Extr.	Complete Sol'n.
S1713	Univ. of UT	5.3±0.2	5.8±0.1	1	1
S1913	Tybo, NV	4.2±0.8	6.3±0.2	2	1
S1912	Cherry Creek, NV	11.1±0.4	8.2±1.6	2	2
S1910	Timber Mtn., NV	5.1±1.1	6.5±0.2	3	1
S1909	Panaca, NV	4.6±2.5	4.3±0.1	3	1
S1901	Baker, NV	9.0±0.7	9.0±0.1	2	2
S1899	Eureka, NV	19.3±0.3	20.0±0.6	2	1
S1892	Vernon-Eureka, UT	4.0±0.1	4.6±0.2	2	1
S1891	Wales, UT	4.3±0.1	2.4±0.4	2	1
S1888	Robertson, WY	3.2±0.7	4.0±0.2	2	1

HASL No.	Site	mCi Pu-239,240 per km^2 100 g	1000 g	No. of Analyses 100 g	1000 g
S1913	Tybo, NV	3.6±0.3	4.7±0.1	1	1
S1912	Cherry Creek, NV	11.4±0.8	10.8±0.3	1	1
S1911	Timber Mtn., NV	3.5±0.2*	4.2±0.1	1	1
S1910	" " "	4.8±1.5	5.6±0.2	2	1
S1909	Panaca, NV	3.1±0.1	7.5±0.2	2	1
S1908	St. George, UT	3.1±0.2	3.3±0.2	1	1
S1907	Panguitch, UT	2.5±0.2	2.4±0.1	1	1
S1906	W. Milford, UT	2.1±0.2	2.4±0.1	1	1
S1901	Baker, NV	9.5±0.6	8.5±0.4	1	1
S1902	" "	5.0±0.5	4.9±0.2	1	1
S1900	Ely, NV	5.8±0.5	5.1±0.2	1	1
S1899	Eureka, NV	19.0±1.7	19.6±0.4	1	1
S1898	Elko, NV	2.1±0.2	2.7±0.1	1	1
S1897	Wendover, NV	2.2±0.2	2.0±0.1	1	1
S1892	Vernon-Eureka, UT	3.9±0.4	4.1±0.1	1	1
S1893	" " "	6.4±0.6	3.6±0.1	1	1
S1891	Wales, UT	4.3±0.4	4.3±0.2	1	1
S1890	Vernal, UT	1.5±0.2	1.9±0.1	1	1
S1888	Robertson, WY	2.7±0.4	3.7±0.1	1	1
S1889	" "	2.8±0.3	4.6±0.1	1	1
S1887	Cache N.F., UT	4.2±0.4	4.4±0.2	1	1
S1886	Twin Falls, ID	2.3±0.3	2.7±0.1	3	1

*Excluded 16.1 mCi/km^2 value.

TABLE B-3. COMPARISON BETWEEN COMPLETE DISSOLUTION OF 10 AND 100 g ALIQUOTS IN SOIL Pu ANALYSIS

HASL No.	Site	mCi Pu-239,2- per km^2 10 g	100 g
S1912	Cherry Creek, NV	9.4±0.8	7.1±0.3
S1901	Baker, NV	9.1±0.6	9.0±0.3
S1903	" "	7.4±0.5	6.6±0.2

(Each value represents a single analysis.)

TABLE C-1. ANALYTICAL QUALITY CONTROL ASSOCIATED WITH ANALYSES OF SOILS

Pre-bomb Soil. No. C-3866			
Aliq. wt. (g)	Lab.	Method	dpm Pu-239,240 per g
100	HASL	Acid extr.	0.0002±100%
100	"	" "	0.0001±100%
1000	LFE	" "	0.0004±14%
	Avg. of previous data		0.0002±100%

Aliq. wt. (g)	Lab.	Method	dpm Cs-137 per g
300	HASL	Ge-Li	0.02±100%
315	"	"	0.01±100%
310	"	"	0.02±100%
	Avg. of previous data		0.04±100%

Brookhaven, NY Reference Soil, No. S1815
Sampled Nov. 1972, 0-30 cm Composite

Aliq. wt. (g)	Lab.	Method	dpm Pu-239,240 per g	mCi Pu-239,240 per km²	Mass Ratio Pu-240/Pu-239
100	HASL	Acid extr.	0.011±10%	2.2	
100	"	" "	0.012±9%	2.3	
1000	LFE	" "	0.011±4%	2.2	0.178
Avg. of previous data			0.012±10%	2.3	

Aliq. wt. (g)	Lab	Method	dpm Cs-137 per g	mCi Cs-137 per km²
364	HASL	Ge-Li	0.72±3%	140
373	"	"	0.65±7%	130
Avg. of previous data			0.78±3%	150

TABLE C-3. ANALYTICAL QUALITY CONTROL ASSOCIATED WITH ANALYSES OF SOILS

N. Eastham, MA. Reference Soil, No. S1781*
Sampled Oct. 1972, 0-30 cm Composite

Aliq. wt. (g)	Lab.	Method	dpm Pu-239,240 per g	mCi Pu-239,240 per km²	Mass Ratio Pu-240/Pu-239
100	HASL	Acid extr.	0.012±10%	2.2	
100	"	" "	0.013±10%	2.3	
1000	LFE	" "	0.014±3%	2.4	0.176
Avg. of previous data			0.013±10%	2.3	

Aliq. wt. (g)	Lab.	Method.	dpm Cs-137 per g	mCi Cs-137 per km²
384	HASL	Ge-Li	0.72±5%	130
395	"	"	0.75±3%	130

*Aliquots taken from original 3 kg that were pulverized in 1972.